Vortex Generation Due to Coastal and Topographic Interactions and Numerical Studies of Internal Wave Dynamics

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LONG-TERM GOAL

Our basic goal is to achieve a better understanding of the turbulent flow of the oceans in terms of the laws that govern the behavior of vortices and waves and their interactions. Our program of research investigates how vortices and waves evolve and interact subject to oceanographically relevant forces. In particular, we are aiming at a better understanding of how internal wave energy propagates through the spectrum of physical scales and how it propagates from the deep ocean to the shallow coastal zones. Also we wish to understand the processes by which vortices and currents are generated in coastal regions.

OBJECTIVES

In our internal-wave project, we are trying to answer several basic questions: How is energy transferred from large-scale perturbations down to the smallest scales where dissipation occurs? Can the range of behaviors observed in isopycnal separation statistics be captured in large-eddy simulation models? How do flow and density fluctuation statistics change as the depth of the ocean varies.

In our project on coastal interactions, the questions that we are trying to answer have to do with how the presence of a coast affects the basic processes involved in the evolution of vortices and currents. We wish to determine the role coastal topography plays in generating vortices and deflecting vortices incident on the coast. Further, we wish to understand the role that coastal topography plays in permitting or inhibiting the bifurcations of coastal currents.

APPROACH

These investigations involve analytical, numerical and laboratory studies. In our coastal current investigations we have used spectral, finite difference and point vortex (particle-in-cell) methods to simulate quasi-geostrophic and shallow-water dynamics near a coast. Transform methods and perturbation techniques have been used to provide analytic solutions in both quasi-geostrophic and shallow-water theory. Laboratory experiments have been performed with a rotating tank to verify the theoretical and numerical predictions. In our internal-wave investigations, we are performing simulations with both spectral and finite-difference three-dimensional simulation codes with a variety of subgrid scale models. Oceanic observations will be used to set the physical parameters for the simulations. Statistics of the three-dimensional fields resulting from the simulations will be compared with the observational data sets.

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WORK COMPLETED

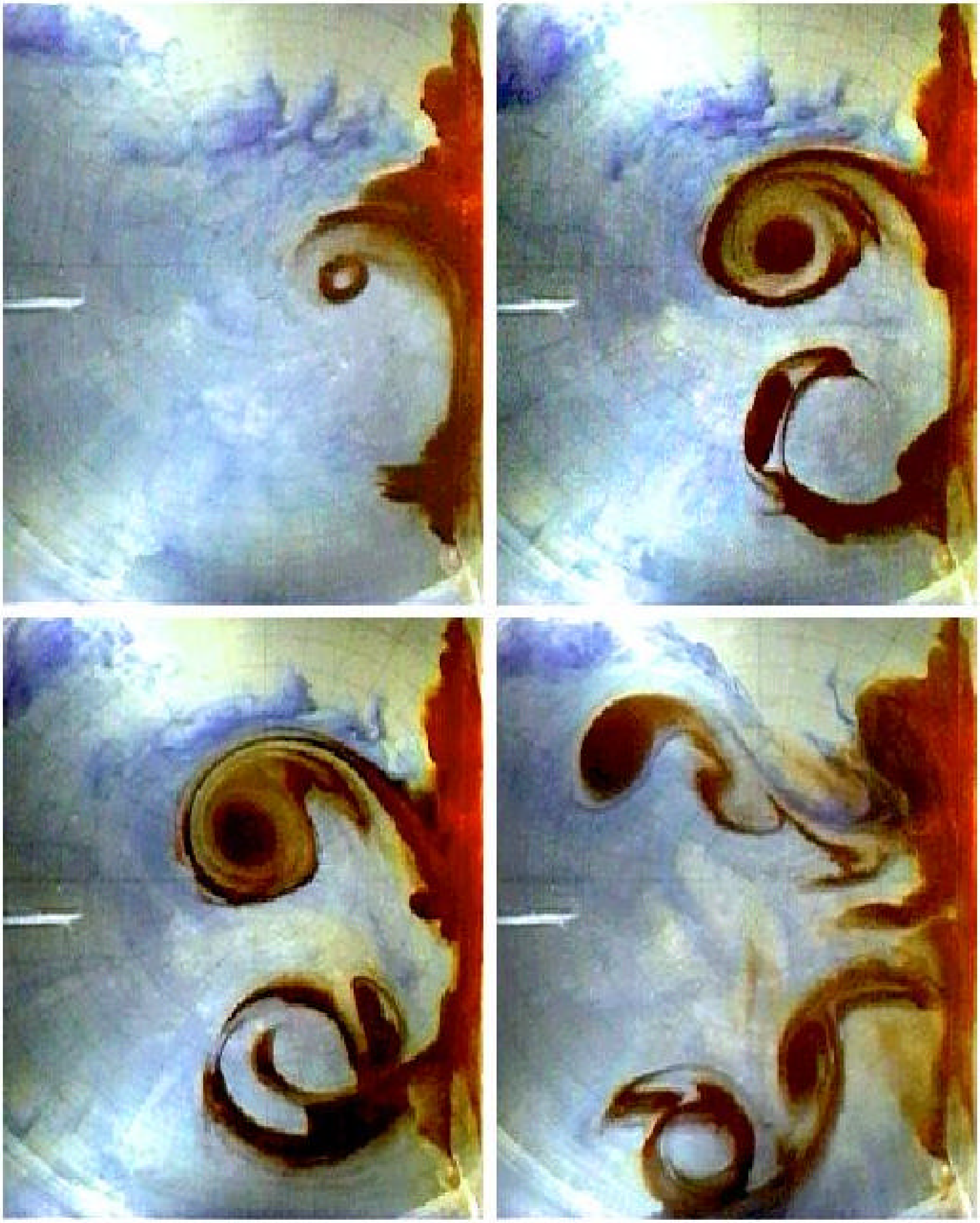
We have performed a series of numerical simulations exploring the collision of a dipolar vortex with a coast. The primary focus of this investigation was to determine the relative importance of the beta-effect and vorticity generation at the coast with regard to the possible rebound of vortices from the coast. The beta-effect here is taken in a generalized sense referring either to the planetary beta-effect resulting from the curvature of the earth, or to a topographic beta-effect resulting from a gradual spatial change in the depth of a rotating fluid. This study is reported in Carnevale, Fuentes and Orlandi 1997.

For the problem of vortex generation by a boundary current over topography, we developed a finite-difference quasi-geostrophic code with radiation boundary conditions on the sides away form the coast. This code was used in a series of simulations to determine the simplest conditions under which the presence of a step-like topography aligned perpendicular to the coast will cause generation of vortices in a coastal current and the generation of offshore flow along the topography. As part of this project, we have solved analytically the steady-state quasi-geostrophic problem for an idealized escarpment or step that intersects the coastline perpendicularly. A paper on this work is now in press (Carnevale, Llewellyn Smith, Crisciani, Purini, and Serravall, 1998) In addition to the analytical and numerical studies of coastal flow across an escarpment, we have also performed a series of laboratory experiments in a rotating tank. These tend to confirm the numerical and analytical results.

For the study of stratified turbulence, we have developed two-basic codes with periodic boundary conditions. One is a finite difference code and the other is a spectral code. The subgrid scale parameterizations used in these codes should permit simulation of fine scale motions from the range of tens of meters down into the inertial range. A series of simple decay experiments were performed with the spectral code that permitted fine tuning of the subgrid scale parameterization. Then we turned to the problem of continuous forcing. We performed some preliminary simulations of a flow driven by large-scale internal waves (e.g. 20 m in the vertical) with energy cascading down into the inertial range.

RESULTS

Through numerical simulations and laboratory experiments, we have measured how the point of separation of a vortex from the coast in the dipole-rebound problem varies as a function of beta. A simple analytical model was proposed to explain this dependence. This model provides a criterion for determining in which situations the beta-effect will dominate over the viscous boundary layer effect in vortex rebound. With regard to the amount of fluid that leaves the coastal region, we have made measurements as a function of beta and also the angle of incidence. The results show that when the beta-effect dominates, the amount of fluid that is lost permanently from the coastal zone is approximately the same as the amount of fluid contained in the original dipole and is roughly independent of beta and the angle of incidence. An example of vortex rebound due to the beta-effect in a laboratory experiment is illustrated in the accompanying figure (Carnevale, Fuentes and Orlandi, 1997).



Dipole Rebound in a rotating tank. The view is from above, along the axis of rotation. The bottom of the tank has a constant slope with the shallower fluid toward the top of each frame. The bright straight line on the left of each frame marks the source of the jet of uncolored fluid that produces the dipolar vortex. When the dipole collides with the wall on the right, it entrains some of the red dyed fluid at the wall. The vortices then rebound from the wall carrying away some of the wall fluid.

For the problem of coastal flow over an escarpment, we found very different results in two seemingly very similar geometries. If, when looking from deep to shallow fluid, the coast is found on the right (left), we refer to this as the right-handed (left-handed) geometry. Our theoretical and numerical results suggested that a coastal current encountering an escarpment in the right-handed geometry would simply bifurcate with part of the current flowing out from the coast along the escarpment, and the rest following the coast. In the left-handed geometry, repeated dipole production should be expected with the eddies propagating away from the escarpment and the coast, on the upstream side of the escarpment, with no outward flow along the escarpment. These predictions were verified in a series of rotating tank experiments.

In our numerical simulations of statistically stationary stratified turbulence, we have forced the flow by causing the internal modes with longest wavelength to evolve as if they were purely linear internal waves. This generates a cascade of energy to small scales that fills out the kinetic and potential energy spectra. We have made some preliminary comparisons of the statistics of the fields so produced with oceanic data on density fluctuations and vertical velocity provided by R. Pinkel and M. Alford. Some encouraging qualitative agreement was obtained, for example, in the probability distributions for inverse Richardson number. However, the results also made it clear that careful tuning of the forcing and the subgrid scale model will be needed to obtain quantitative comparisons.

IMPACT/APPLICATION

The results on vortex collisions with a coast may be useful in understanding the relative roles of the beta-effect, viscous boundary layer effects, and topography in determining the trajectories and evolution of vortices near coasts. Since the relationships between these effects vary with latitude, our results may help explain, in part, the variation of the character of the turbulent boundary current as a function of latitude.

Our results on coastal current bifurcations due to topography may be useful in analyzing the flow in a variety of places where strong topographic variations occur in the along-shore direction. In particular, the flow along the steep side of the Jabuka pit in the Adriatic seems to be a good example of the flow we predicted for the right handed geometry. Our results also explain some unexpected behavior of currents previously found in laboratory experiments on coastal flow over a step.

It is rather difficult to reconstruct the flow structures in any given volume of the ocean from available observational data. For example, various explanations may be offered to explain a particular overturning event seen in a density profile. By observing similar events in a fully three dimensional data set produced by our simulations, we hope to be able to decide on the validity of various hypotheses currently used to explain the occurrence of such events.

RELATED PROJECTS

Our work on internal waves involves comparisons between the data generated in our simulations with actual oceanic observations being made in two separate projects headed by M. Hendershott and R. Pinkel at Scripps Institution of Oceanography. We are aslo collaborating with R. Kloosterziel on internal wave dynamics. He is investigating the propagation of internal waves from localized sources. His predictions, which are based on linear wave dynamics, will be compared to our numerical simulations.

Our laboratory work on coastal current bifurcation is being performed in collaboration with G-J van Heijst and L. Z. Sanson at the University of Eindhoven, and R. Serravall at the University of Rome.

Our numerical simulations are being performed in collaboration with P. Orlandi. In addition to studies of stratified turbulence, we have also been looking at the effects of rotation and density variations on the evolution of vortices.

PUBLICATIONS

Carnevale G.F., Briscolini M., Kloosterziel, R.C., and Vallis G.K., 1997: Three-dimensionally perturbed vortex tubes in a rotating flow, J. Fluid Mech. 341, 127-163.

Carnevale G.F., Fuentes, O.V. and Orlandi, P., 1997: Inviscid dipole-vortex rebound from a wall or coast, J. Fluid Mech. 351, 75-103.

Carnevale, G.F., Llewellyn Smith, S.G., Crisciani, F., Purini, R. and Serravall, R. 1998: Bifurcation of a coastal current at an escarpment. (in press, J. Physical Oceanography)

Carnevale G.F. and Orlandi, P. 1998: Evolution of isolated vortices in a rotating flow of finite depth. (in press, J. Fluid Mech.)

Kloosterziel, R.C. and Carnevale, G.F. 1998: A low-order spectral model for the evolution of planar vortices on an infinite domain. (submitted to J. Fluid Mech.)